THE ANATOMICAL AND RADIOLOGICAL RELATIONSHIP BETWEEN THE PARS INTERARTICULARIS AND THE PEDICLE IN THE LUMBAR SPINE – IMPLICATIONS FOR PEDICLE SCREW INSERTION

Dissertation submitted to the Tamil Nadu Dr.M.G.R Medical

University in partial fulfillment of the requirement for the

M.S Degree Examination Branch II (Orthopaedic Surgery)

May 2018

CERTIFICATE

This is to certify that the dissertation entitled "**The Anatomical And Radiological Relationship Between The Pars Interarticularis And The Pedicle In The Lumbar Spine – Implications For Pedicle Screw Insertion."** is original work done by

Dr. Chandan. N

Done under my guidance towards the M.S Branch (Orthopaedics) Degree

Examination of the Tamilnadu Dr. MGR Medical University, Chennai to be held in

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DECLARATION CERTIFICATE

This is to declare that the dissertation titled "The anatomical and radiological relationship between the pars interarticularis and the pedicle in the lumbar spine – implications for pedicle screw insertion", in the department of Orthopedics is my own work, done under the guidance of Dr. Kenny S. David, Professor and Head Spinal Disorders Unit, submitted in the partial fulfillment of the rules and regulation for the M.S Orthopedics degree examination of the Tamilnadu Dr. M.G.R Medical University, Chennai to be held in May 2018

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ACKNOWLEDGEMENTS

I thank God for His enabling grace that helped me in completing this work all the people who helped in this process.

I express my sincere thanks and heartfelt gratitude towards Dr. Kenny S. David, Professor & Head, Spinal Disorders, for being my guide and directing me to work on this unique topic as a part of my thesis. He has always been patient enough to listen and take time out of his busy schedule towards working on this project. I had great time working along with him and thankful for the timely help he extended when it was needed. He constantly supported and directed me towards the completion of the thesis in spite of my short comings, and I shall always be grateful to him.

I shall remain indebted to Dr. Dr.Suganthy Rabi Professor & Head, Department of Anatomy for providing me the needed cadaver specimens, place and freedom to work, without her help it would have been impossible to proceed further in this project.

I also extend my sincere thanks to Dr.Madhavi Assistant Professor and Dr Soumya Susan Regi Assistant Professor from the Department of Radiology for their efforts in providing with the radiological measurements in spite of their busy schedule.

I also extend my gratitude to Dr. Arul Parathasarathy RM Fellow, Spinal Disorders Surgery Unit. His help in dissecting the cadaveric specimens is noteworthy. It was a wonderful experience doing the study with him and something I shall fondly remember.

I also thank Dr Venkatesh, Dr. Rohit Amritanand and Dr Justin in providing me useful insight into my study and providing the necessary constructive criticism and moral support.

It was my privilege to have received training from various experienced faculty from the Department of Orthopaedics for their amazing advice and teaching throughout the training period.

I thank my colleagues, seniors and juniors for their constant support.

And last, but not the least my parents, sisters and special mention of my wife Dr.Rebecca for her constant encouragement and prayers.

Contents

AIM:

To describe the relationship between pars interarticularis with the pedicle in lumbar vertebra and to use that relationship as a consistent landmark for pedicle screw insertion between T12 and L4 vertebra.

OBJECTIVE:

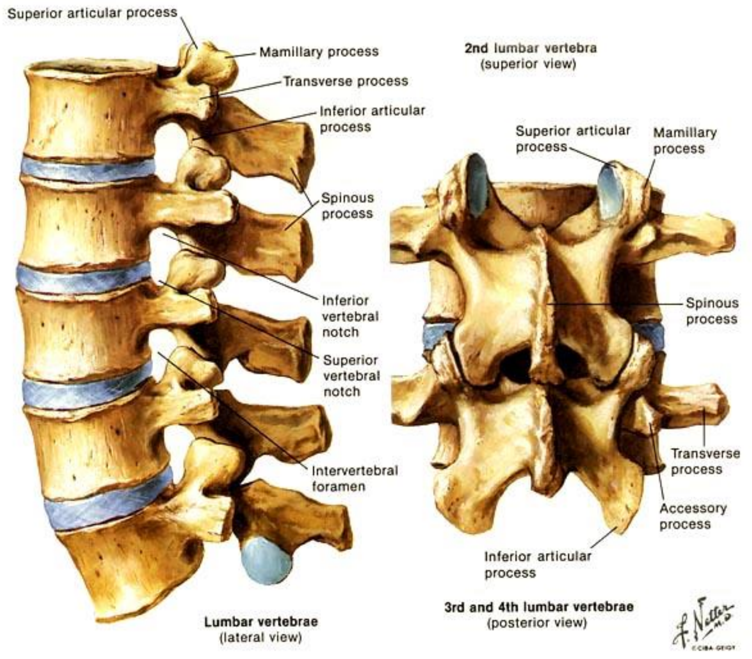
To demonstrate that the lateral border of the pars interarticularis can be used as a consistent and reproducible anatomical landmark between T12 to L4 vertebra to guide pedicle screw placement.

INTRODUCTION:

Anatomy of Lumbar Spine:

"Lumbar" is derived from the Latin word "lumbus," meaning lion and is designed for both stability and flexibility - lifting, twisting, and bending.

The lumbar spine is made up of 5 vertebral segments, termed lumbar segment (L1-L5).



Characteristics of Lumbar Spine:

The five vertebrae of the lumbar spine (L1-L5) are the biggest and unfused vertebrae in the vertebral column, enabling them to support the weight of the entire torso.

Through the lower segments, L4-L5 and L5-S1, most of the body weight gets transmitted and are more prone for degenerative changes.

The lumbar spine forms the lumbosacral joint at sacrum (L5-S1) this allows for considerable rotation, so that the pelvis and hips may swing when walking and running.

The vertebral bodies are large and kidney-shaped. They are deeper anteriorly than posteriorly, producing the lumbosacral angle (the angle between the long axis of the lumbar region and that of the sacrum).

Parts of lumbar vertebrae:

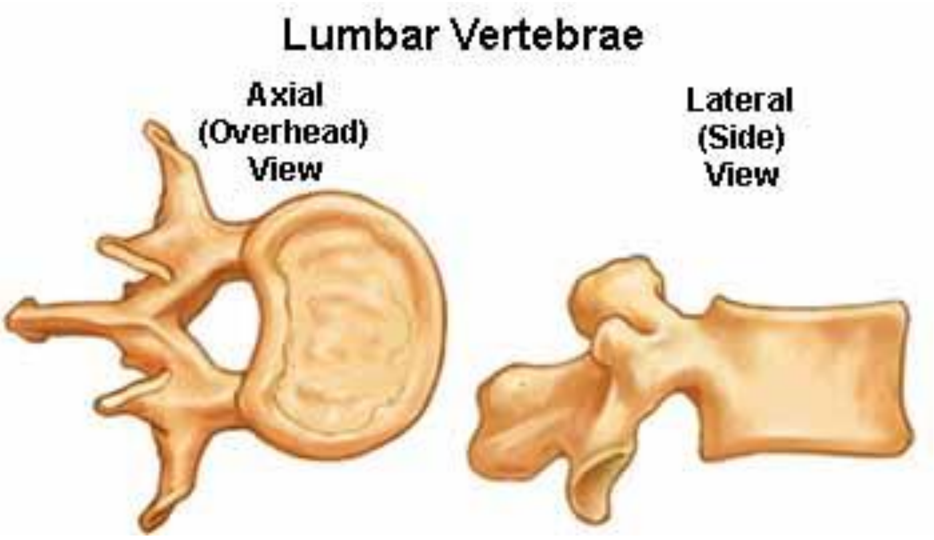
Transverse processes are long and slender.

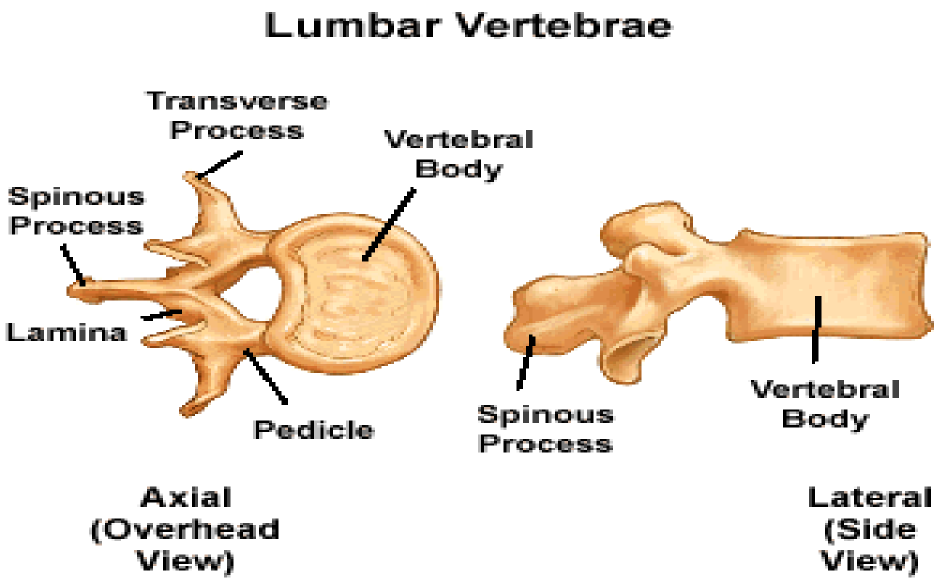
Articular processes have nearly vertical facets.

Spinous processes are short and broad.

Accessory processes can be found on the posterior aspect of the base of each transverse process. They act as sites of attachment for deep back muscles.

Mammillary processes can be found on the posterior surface of each superior articular process. They act as sites of attachment for the muscles.





<u>Joints:</u>

There are two types of joint in the lumbar spine.

Between vertebral bodies – adjacent vertebral bodies are joined by intervertebral discs, made of fibrocartilage. This is a type of cartilaginous joint

Between vertebral arches – formed by the articulation of superior and inferior articular processes from adjacent vertebrae. It is a synovial type joint.

Ligaments:

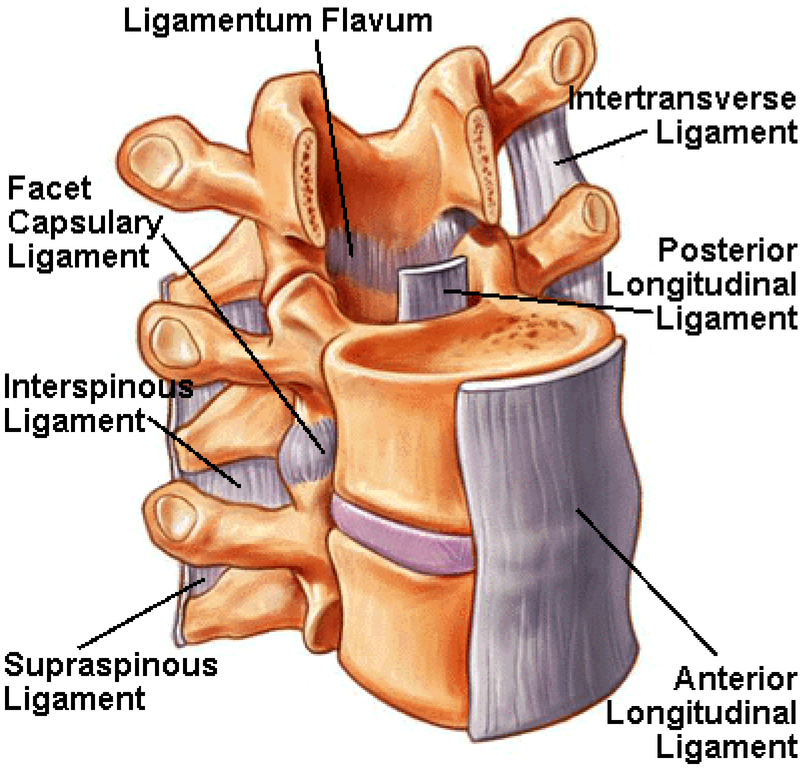
The joints of the lumbar vertebrae are inter connected by several ligaments. They can be divided into two groups; those present throughout the vertebral column and those unique to the lumbar spine.

Anterior and posterior longitudinal ligaments: Long ligaments that run the length of the vertebral column, covering the vertebral bodies and intervertebral discs.

Ligamentum flavum: Connects the laminae of adjacent vertebrae.

Interspinous ligament: Connects the spinous processes of adjacent vertebrae.

Supraspinous ligament: Connects the tips of adjacent spinous processes.



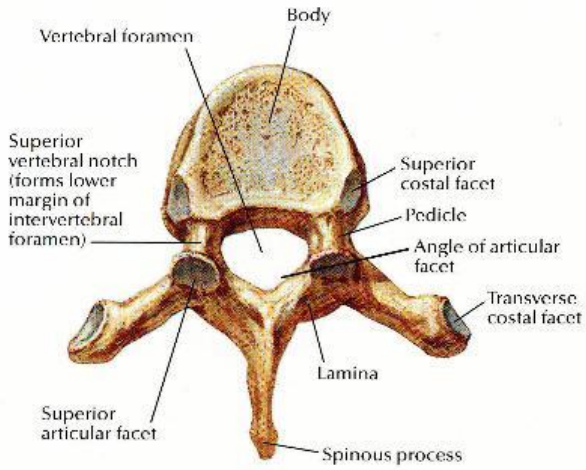
The lumbosacral joint (between L5 and S1 vertebrae) is strengthened by the iliolumbar ligaments. These are fan-like ligaments radiating from the transverse processes of the L5 vertebra to the pelvis

The vertebral foramen is triangular in shape through which neural elements pass

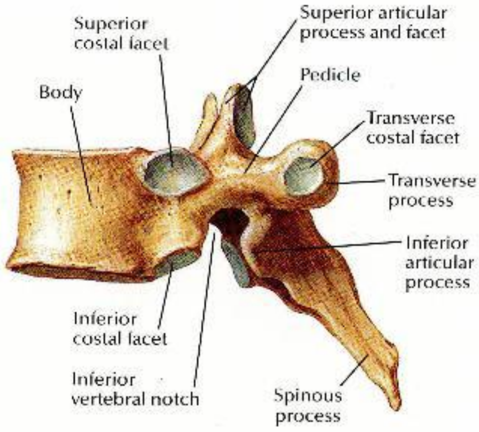
The spinal cord travels from the base of the skull through the spinal column and ends at about T12-L1, where the thoracic spine meets the lumbar spine. At this junction numerous nerve roots from the spinal cord continue down and branch out, forming the “cauda equina" named for its resemblance to a horse tail.

T12-Thoracic Vertebra:

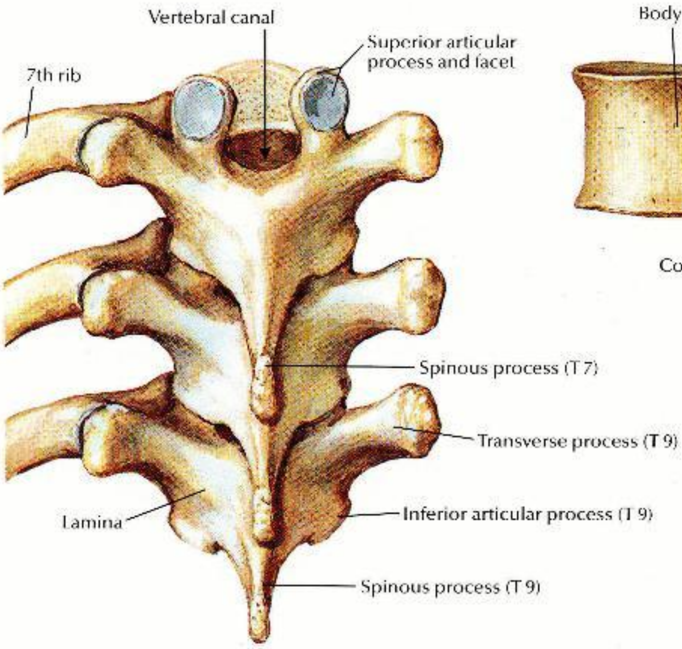
The twelfth thoracic vertebra (or the T12 vertebra) is the largest of the thoracic vertebrae. T12 bears the most weight of any thoracic vertebra, making it the strongest thoracic vertebra, but also more prone for injuries due to the transitional nature from more rigid to more mobile segment of the spinal column. T12 vertebra has anatomical features of both a thoracic and lumbar vertebra. Its structure is similar to the other thoracic vertebrae, with a large column of bone known as the centrum (or vertebral body) forms its anterior structure and a thin ring of bone known as the vertebral arch forming its posterior structure.



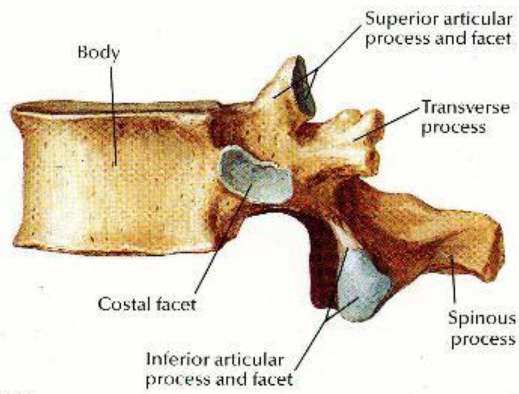
6th thoracic vertebra: superior view



6th thoracic vertebra: lateral view



7th, 8th and 9th thoracic vertebrae: posterior view



12th thoracic vertebra: lateral view

The vertebral body is larger and wider in T12 than in the other thoracic vertebrae and more closely resembles the vertebral bodies of the lumbar vertebrae.

It is flat on top and bottom, convex anteriorly, and slightly concave posteriorly.

The vertebral arch of T12 is thicker and stronger than its counterparts in the other thoracic vertebrae and in many ways resembles the vertebral arches of the lumbar vertebrae.

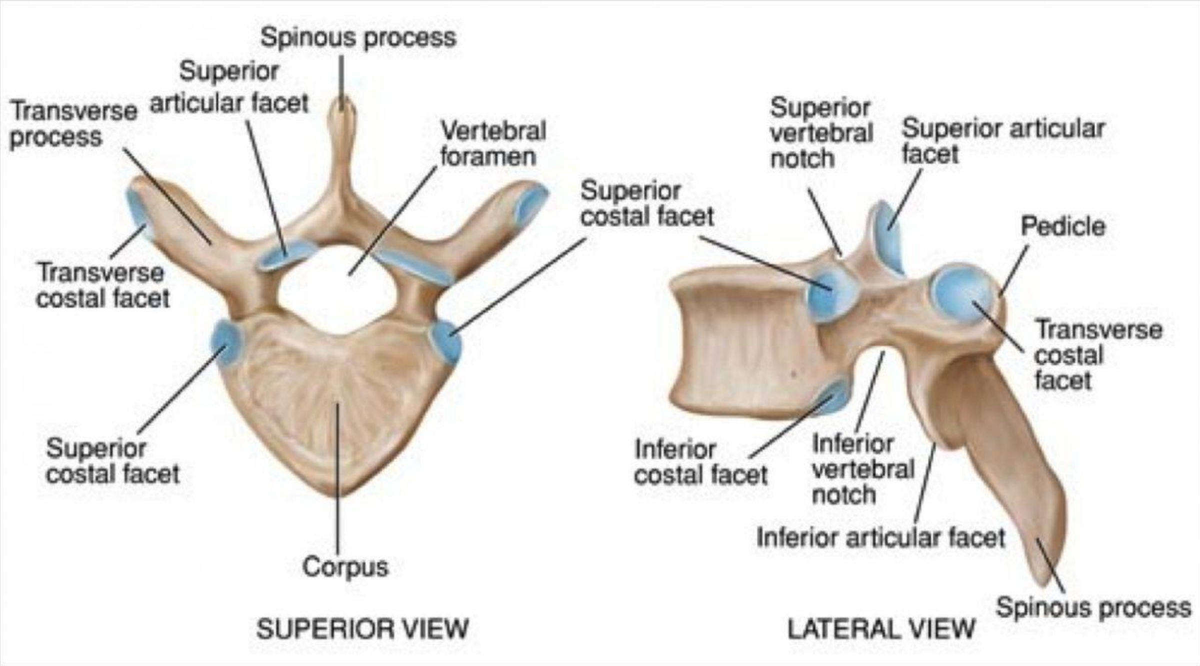
A pair of strong pedicles extends posteriorly from the vertebral body to begin the neural arch.

Each pedicle contains a smooth, oval-shaped articular facet that forms a joint with the 12th pair of ribs.

Posterior to the pedicles are the transverse processes that extend laterally from the vertebral arch.

Unlike the transverse processes of the superior thoracic vertebrae, those of T12 are short; they do not form joints with the ribs; and they end in three tiny processes – the superior, lateral and inferior tubercles which serve as attachments to the muscles.

The thin laminae continue the vertebral arch posteriorly from the transverse processes until they unite in midline to form the spinous process.



The spinous process is considerably shorter, straighter, and thicker in T12 than it is in the superior thoracic vertebrae, closely resembling the spinous process of the lumbar vertebrae below.

Extending vertically from the vertebral arch are two pairs of articular processes that form joints with the adjacent vertebra and helps in stabilizing the spine.

The superior articular processes extend superiorly to meet the inferior articular processes of the T11 vertebra.

Each superior articular process resembles those of the thoracic vertebrae, ending in a smooth, convex oval that corresponds with the concave oval of the inferior articular process of T11.

The joints formed between T11 and T12 are termed as planar joints, and allow the bones to glide along a plane relative to one another.

Inferiorly the T12, has a pair of inferior articular processes descends to meet the superior articular processes of the L1 vertebra. The inferior articular processes resemble those of the lumbar vertebrae, ending in smooth cylinders of bone that are surrounded by cup-like ends of the superior articular processes of L1.

The joints formed between T12 and L1 are reinforced planar joints, which are less mobile and more stable than the T11-T12 joints.

Pars Interarticularis:

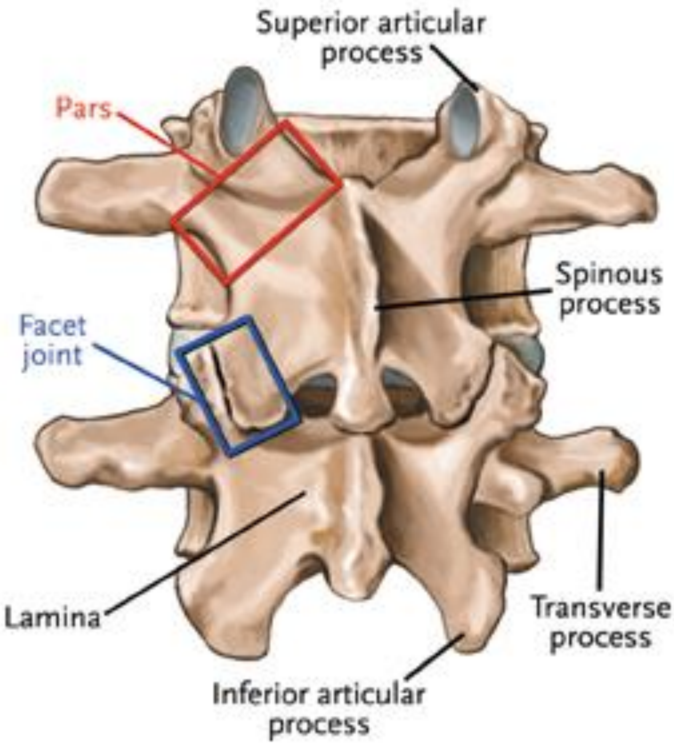
Definition:

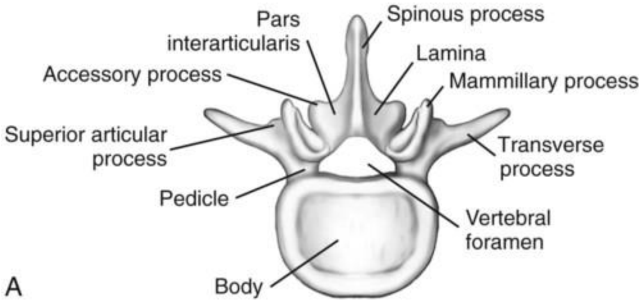
Pars Interarticularis (Latin-bridge between two joints) or pars in short is defined as small segment of bone that connects superior and inferior facet joints in the vertebral column.

In transverse plane pars lies between the lamina and the pedicle and in axial view it forms the bony mass that lies between the superior and inferior facet joints.

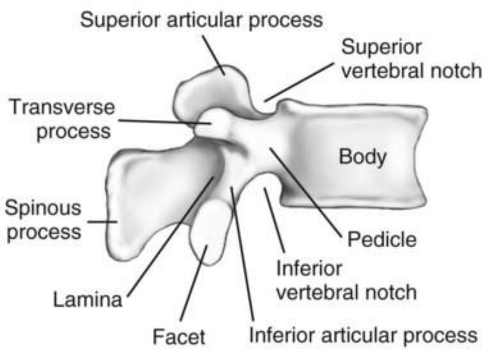
In the cervical spine, pars interarticularis is commonly referred to as the lateral mass, and in the thoroco-lumbar spine, it forms the location where the transverse processes take their origin.

In radiographs of lumbar spine taken in anterior oblique view, pars represents the neck of the imaginary Scottie dog; the Scottie dog's eye represents the pedicle, its nose represents the transverse process, ear the superior articular facet and forelegs the inferior articular facet, hind legs the spinous process respectively.

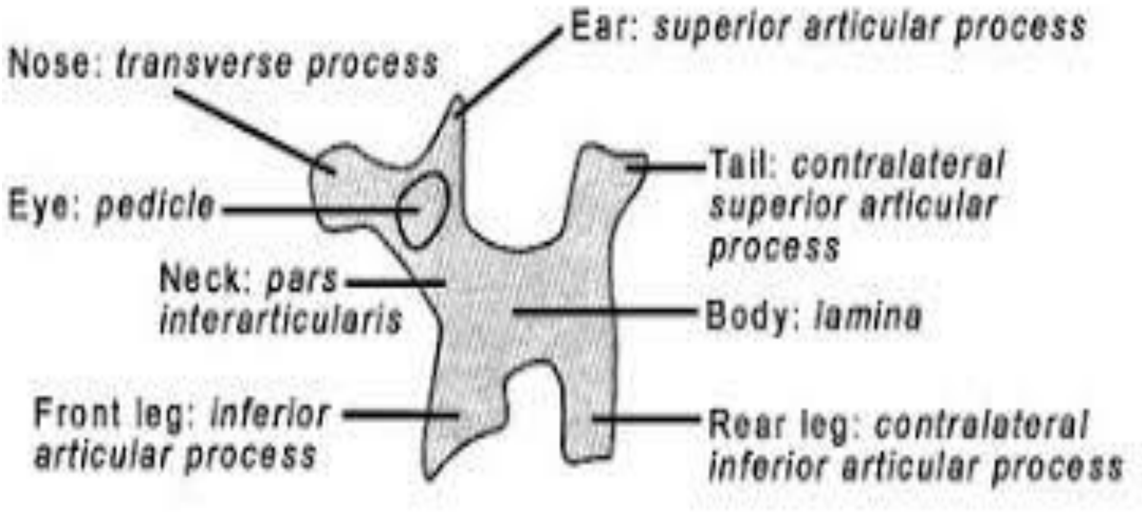

Superior articular process
Pars
Spinous process
Facet joint
Lamina
Transverse process
Inferior articular process


Pars interarticularis
Spinous process
Lamina
Accessory process
Mammillary process
Superior articular process
Transverse process
Pedicle
Vertebral foramen
Body

A


Superior articular process
Superior vertebral notch
Transverse process
Body
Spinous process
Pedicle
Inferior vertebral notch
Lamina
Facet
Inferior articular process

B



LINE DIAGRAM SHOWING PARS AS NECK OF IMAGINARY SCOTTIE DOG

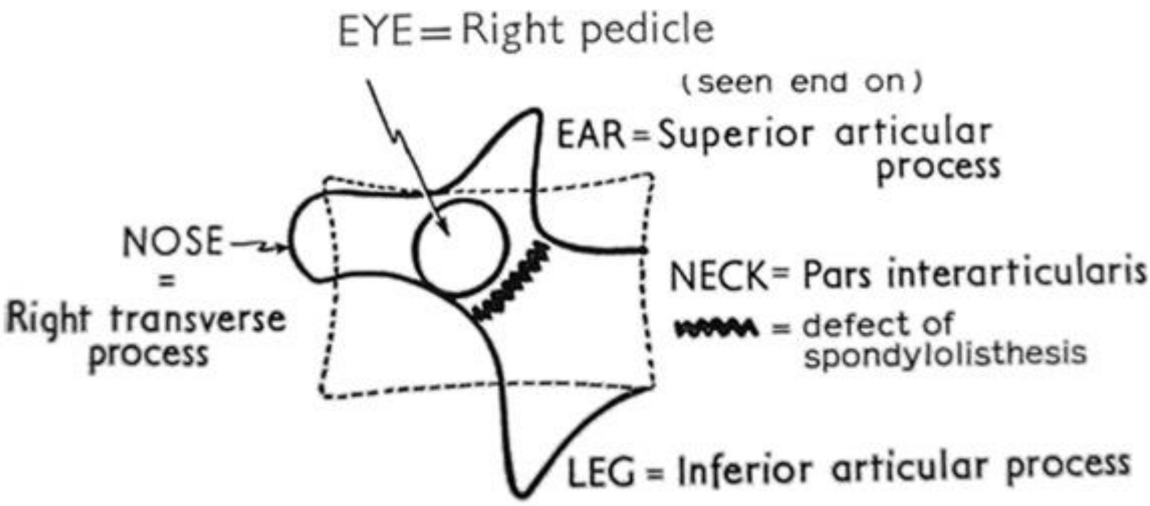


Diagram Showing Defect in PARS

Krenz et al studied the normal anatomy of the pars of 4^{th} and 5^{th} Lumbar vertebra in seven cadaver specimens and described pars is made up of two dense cortical layers antero-lateral and postero-medial; the antero-lateral being the thickest part (1). And the trabeculae present in between the antero-lateral and postero-medial layers appear to be stronger than in the rest of lamina which might be the reason that pars can withstand considerable amount of stress.

Anatomically, pars forms the narrowest part of the bony arch, and Bio mechanically pars is subjected to high stresses during adjacent segment movement in the vertebral column and has its own important clinical implications. In a C2 Hangman's type fracture, the pars is the segment of the bone that fractures, and in lumbar spine, stress fracture through the pars is termed as spondylolysis.

There are significant number of anatomical and morphological studies mostly focused on the vertebral body, pedicles, spinal canal, and the relationship of the pedicles to spinal canal. Till date there is limited data available regarding the pars interarticularis and its relationship to the surrounding structures.

The role of pars interarticularis in maintaining the structural integrity of the vertebral column is shown in various studies. Ranu et al analyzed the amount of stress on the pars on in-tact and post laminectomy vertebra and found that the pars is subjected to high stress and also shown to increase when the posterior elements are further removed.(2)

Cyron et al shown that the there is increased susceptibility of the pars fracture when subjected to repetitive stress in their study on intact lumbar spine.(3)

Finite element analysis conducted by Ivanov et al from L3-S1 vertebrae shown that when one half of the pars interarticularis is removed there is significant increased stress in the arch in compared to the removal of one fourth of the pars.(4)

Sairyo et al in their bio mechanical analysis of unilateral spondylolysis found increased stresses in the opposite pars. In their further study in 13 athletes of adult age group with unilateral fracture of pars interarticularis and found that 53.8% shown radiological evidence of contralateral sclerotic changes or a stress fracture of the pars.(5)

Pars playing a key role in adding structural support to the spinal column yet there is not much literature available on its anatomic feature and its relationship to the surrounding spinal canal structures.

LITERATURE REVIEW

A variety of disease conditions in the spine, congenital, degenerative, traumatic, neoplastic, results in unstable spine which may lead to unrelenting pain being a mechanical cause, nerve root compression or a progressive deformity which may not be fully addressed by non-operative management there by requiring surgical intervention

In order to address the above conditions fusion of spine has been the main stay of treatment, and the most common indications being instability following a trauma, spondylolisthesis causing significant back and leg pain, degenerative lumbar canal stenosis, psuedoarthrosis of spine, tumors being primary or metastatic in nature resulting in instability and neurological compromise when significant portion of vertebral body is involved.

The concept of internal fixation of the spine has gained its significance over the decades from the time of its introduction by Harrington which was used initially for correction of deformity in scoliosis followed by trauma(6). Before the introduction of Harrington instrumentation the pseudoarthrosis rate following scoliosis correction is 30% to 40%.(7) Following the use of Harrington instrumentation to treat scoliosis the pseudoarthrosis rate was 1% to 15%.(8) The purpose of internal fixation of the spine is to aid in stabilization, early fusion rates there by decreasing the pain and morbidity associated with prolonged hospital stay and allowing early mobilization and rehabilitation.

If the above goals can be achieved with limited risk and at affordable costs, such intervention is considered safe and effective for the patient.

With regard to internal fixation of spine various systems have evolved over the period of time starting from Harrington instrumentation, Luque sub-laminar wiring technique(9), Hook fixation by Cortel and Dubousset and each of the instrumentation had their own drawbacks Viz., neurological injury, Dural tears, hook disengagement, wire breakage, canal violation, inability to provide three dimensional stability and in addition the fixation mainly depends upon the presence of intact posterior elements.

The concept of pedicle and facet screw fixation was first reported in 1940's by King D(10) later Boucher(11) used in 1959 and more extensively used by Roy-Camille et.al.,(12) Since then pedicle screw instrumentation is gaining its popularity as its use increased fusion rates, enhanced rigidity, can be used in short and long segment fusion and above all pedicle screw does not require intact posterior elements.

The pedicle is considered as the strongest part of the vertebral body where the posterior elements of the spine converge to form a bony mass which attaches to the anterior portion of the vertebral body. It is described as "Force Nucleus" of the vertebra (13). Being the strongest portion pedicle is considered as ideal point force for pedicle screw placement. When properly placed screw is used along with screw-rod or screw-plate configuration the ability to apply compression, distraction and rotational force across the spinal segments has been greatly increased in order to address various deformities and clinical conditions.

Biomechanics studies have shown the constructs with properly placed screws in the pedicle provide more rigidity compared with other systems of instrumentation(14–16). In addition to rigid fixation pedicle screw constructs allow early mobilization there by decreasing the requirement of rigid orthotic support. After a period of extensive research it was shown that the benefits of pedicle screw instrumentation outweighs the risks involved as they provide greater rotational stability, enhance rigidity and have greater stiffness in flexion and rotation compared to other instrumentation. In addition these constructs can be used with ease in short segment fusion in carefully selected patients based on load sharing classification(17,18) .

With the added benefits of pedicle screw instrumentation compared to other instrumentation currently the pedicle screw instrumentation is broadly used in the following conditions:

1. Stabilization following a decompressive laminectomy in Spondylolisthesis (degenerative).
2. Stabilization of spine following trauma which led to unstable burst fractures
3. Primary or metastatic tumors of the spine needing aggressive resection or decompression which will be needing stabilization
4. In treating Isthmic spondylolisthesis which require reduction and stabilization.
5. Fusion in symptomatic pseudarthrosis

6. Deformity corrections as in scoliosis
7. Certain disease conditions causing nerve root irritation due to rotational instability.

With the improved understanding of the anatomy of the spine, assisted technologies the use of pedicle screw instrumentation is gradually extending in various other disease conditions.

Over the last few decades there is a significant progress in the technique for pedicle screw instrumentation(19) . Initially the use of pedicle screws were confined to Lumbar spine(20), as the instrumentation of the thoracic pedicle remained as a challenge due to its inconsistent shape, narrow width, along with the presence of ribs, vital structures combined with deformities made the placement of pedicle screw technically more challenging. With improved understanding of the complex anatomy of thoracic pedicle the technique for accurate pedicle screw placement has evolved in its use in thoracolumbar and thoracic region (21).

Mattei et al explained regarding the factors which determine the use of pedicle screw in upper and middle thoracic versus thoracolumbar and lumbar levels[TABLE 1](22)

Advantages and Disadvantages of free hand technique for pedicle screw insertion upper and middle thoracic to that of Thoracolumbar and Lumbosacral by Mattei, *et al.*:	
Thoracolumbar and lumbosacral spine	**Upper and middle thoracic spine**
Standard methods were described in placement of pedicle screw	Challenging to place due to complex anatomy
Anterior violations of the screw often less dangerous	Anterior violations of the screw are dangerous as thoracic viscera are adhered to anterior longitudinal ligament
Larger pedicle size gives added advantage	Smaller pedicle size – leading to canal violations

In a given clinical scenario placement of pedicle screw in thoracolumbar region can be technically demanding needing expertise and learning curve with potential risks like canal violation, neurological, vascular and visceral injury. In order to minimize the risks various techniques have evolved over a period of time for the placement of pedicle screw in thoracolumbar region.

These techniques involve the use of bony anatomical landmarks, Lamino-foraminotomy, C-arm Fluoroscopy and various Computer assisted techniques(23–26). These techniques can also be used along with neuro-physiological monitoring methods(27–29).

With the advent of Anatomical studies significant effort was invested in understanding the detail complex morphometry and three dimensional anatomy of thoracolumbar pedicles(30–32)have led to emergence of “Free-Hand” technique of pedicle screw placement which is primarily based on anatomical landmarks(22,33). The accurate placement of pedicle screw using free hand technique require adequate exposure of the anatomical landmarks both visible and palpable. The bony landmarks being lateral border of pars interarticularis, the transverse process, superior and inferior facet joints.

Various authors have shown that with adequate training and expertise thoracolumbar screws can be consistently placed by using free hand technique with minimal risks involved(23,34,35). In one series 3400 thoracolumbar screws were consistently placed without neuro-vascular complications and with 6% breech rate(33,36,37) . It is stressed that while placing a pedicle screw a surgeon should be aware of various bony landmarks, carefully review the entry point and screw direction in sagittal and axial plane.

Several spine surgeons published various entry points and screw placement methods. In general while instrumenting between T12 to L4 the most commonly used landmarks are lateral border of pars interarticularis, transverse process, superior facet joint and the optimal point for the pedicle screw entry is at the junction of pars interarticularis, midpoint of transverse process and the inferior margin of the superior articular facet joint.

Roy Camille(12) used the point of intersection between the lines drawn along the facet joint and the transverse process as an entry point which was used by Silberman et al(38) in 2011 for various spine diseases and reported an accuracy rate of 94.1%.

In Margel's (39) technique entry point lies at the junction of lateral border of superior articular process and a line drawn bisecting the transverse process which was used by Su et al(40),in 2012 and reported 93.5% accuracy in scoliosis patients.

Beck et al in 2009 and Parker et al in 2011(41)used Du and Chao method the entry point being junction of pars interarticularis with the mammillary process and transverse process and reported accuracy rate of 96.8 % and 99.1% respectively.

Karapinar et al(37)in 2008 used Levin and Edwards method the entry point was at the intersection of transverse process with the midpoint of middle and lateral one third of superior articular facet corresponding to the same vertebra and reported 97.7% accuracy.

In Kim's Method(36)the entry point is at the junction of the proximal edge of the transverse process and lamina in order to overcome the errors caused in presence of hypertrophied facet joint while determining the entry point by traditional methods. The landmarks used by Kim are not affected by presence of hypertrophied facet joint.

Weinstein et al (23) found that the Roy-Camille technique was successful in the thoracolumbar junction (T11–L2), but in lower lumbar spine L3-S1 resulted in medial pedicle breech and he recommended the starting point for entry to be more lateral, starting at the nape of the neck which corresponds to infero-lateral corner of the superior articular facet.

Hou et al(42) reported that as with caudal progression, the entry point should move laterally.

Ebraheim et al(43) in their morphometric analysis of lumbar pedicle found that with caudal progression, in the midline the starting point lies more inferior to the transverse process.

Instrumenting upper and middle thoracic spine by free hand technique remained as a challenge due to its narrow sized pedicle, complex morphometry which lead to screw malposition, pedicle breech, and injury to surrounding vital structures. These can be minimized by using intra operative navigation methods like fluoroscopy etc. Early studies by Vaccaro et al advocated to restrict the use of pedicle screw in thoracic spine only in specific clinical circumstances owing to its complications(44,45).

But the radiation exposure to the surgeon, patient and operating time being the main concern and with the improved understanding of the complex morphometry of the thoracic spine free hand placement of the pedicle screws using the anatomical land marks has been the preferred modality while instrumenting the thoracic spine. Various surgeons defined different entry points while instrumenting the thoracic spine as shown below. Table 2

Table 2: Table describing entry points by various authors for free hand technique placement of thoracic pedicle screw.

Author	Entry point
Kim, et al. (2004)	T1-T2: junction of the transverse process and lamina at the lateral pars interarticularis; T3-T6: getting more lateral and caudal; T7-T9: junction of proximal edge of the transverse process and lamina just lateral to the midportion of the base of the superior articular process; T11-T12: junction

	of the transverse process and lamina or just medial to the lateral aspect of the pars interarticularis.
Karapinar, et al. (2008)	T10, T11, and T12: The junction of a vertical line along the lateral pars boundary and a transverse line dividing the transverse process in half.
Modi, et al. (2009)	The junction of the outer third and inner two-thirds of the superior facet joint taken at the junction of the lateral and medial thirds of the facet joint after observing the whole facet joint margin
Modi, et al. (2010)	The junction of the outer third and inner two-thirds of the superior facet joint taken at the junction of the lateral and medial thirds of the facet joint after observing

	the whole facet joint margin
Parker, et al. (2011)	The center of a triangular bony confluence formed by the superior articular facet, the transverse process, and the pars interarticularis
Rivkin, et al. (2014)	T1 only: medial and superior to the intersection of the transverse process and pars interarticularis
Fennell, et al. (2014)	For each level: 3 mm caudal to the junction of the transverse process and the lateral margin of the superior articulating process

Mauricio et al(46) analyzed various entry points used by different authors and reported that free hand thoracic placement of the pedicle screw is safe and effective with proper mastering of the anatomical land marks there by decreasing the radiation hazards and operating time. In their study they further proposed more uniform parameters that make free hand technique easy and simple.

Parker et al(41) retrospectively analyzed 6816 consecutive screws placed in thoracic and lumbar spine by free hand technique and found that breech rate is more frequent in thoracic spine than compared to lumbar and lowest in L5 and S1. In conclusion they reported free hand placement of pedicle screw can be performed with acceptable safety and accuracy avoiding radiation.

Michael J Elliot et al in their cadaveric study reported that when thoracic screws are placed along the anatomical axis of the pedicle is safe without neurovascular injury(47).

In one of the recent meta-analysis looking at the studies done between 1990 to 2009 demonstrated accuracy of 89.2% of 7553 placed pedicle screws(48).

V. Puvanesarajah et al recommended to use free hand technique when instrumenting outside mid thoracic region and when placing screws in mid thoracic region with significant deformity should be guided by navigation methods in order to ensure accuracy in placing the screws without complications(49).

Of all the entry points proposed by various authors over the years pars interarticularis is found to be common anatomical structure which was used as one of the guide in defining the entry point for pedicle screw placement.

To our knowledge very few studies had been done on the anatomical characteristics of pars interarticularis in relation to the pedicle in spine and no study has specifically documented the relationship between the lateral border of the pars and the medial border of the pedicle.

Wiener BK et al(50)in 2002 provided descriptive and anatomical data on “The Lateral Buttress of pars-interarticularis in Lumbar Vertebrae” (Lateral Buttress is described as bony bridge connecting the superolateral edge of the inferior articular facet extending cephalad and anteriorly to the undersurface of the junction between transverse process and pedicle) and the surface area is broader as one moves from L5 to L1and there by drawing its clinical and surgical implications. As the surface area is broad at upper levels it can result in placing the pedicle screw laterally in spite of following well-described anatomical landmarks in pedicle screw placement. In lower lumbar levels since the buttress is small and provides minimal support one has to be careful during laminectomy as aggressive laminectomy will result in iatrogenic instability.

Vaccaro et al in 2008(40)in their Anatomical study described the relationship between pedicle centre to the Mid-Lateral pars in lower Lumbar vertebra as a guide to pedicle screw placement and concluded that mid lateral pars is a reliable anatomic reference.

According to McCulloch et al(51) In intertransverse interval the lateral border of the pars interarticularis is on the same Sagittal plane as the medial border of the pedicle for L1 to L4 except for L5 where it lies at the centre of the pedicle.

E.Yee et al(52) in 2010 measured the remnant of the lumbar pars from the medial edge of the pedicle and found that gradual narrowing of pars interarticularis as one moves from L5 to L1(in which case we can indirectly derive the distance measured from lateral border of the pedicle to medial border of the pars.)

Austin Peters et al (53)in 2014 measured the distance between the pars interarticularis in Lumbar specimens and demonstrated that the interpars distance increased gradually from L1 to L4 and more across L4-L5

El-Rakhawy et al(54) measured the inter pedicular distance in Lumbar spine using computed tomography and the average distance was found to be 21.6mm at L1 to 25.1mm at L5, which shows the distance remained nearly constant as one moved from L1 to L5 without significance difference

Yale Kapoor et al(55) in their morphometric analysis on dried lumbar vertebrae calculated the inter pedicular distance and found to be a mean of 18.51 mm at L1 and 21.5 at L5 and 21.47 in between L2-L4.

Tarek Aly et al(56) in their geometric and morphological study of lumbar canal in normal Egyptian population measured the midsagittal diameter, lateral recess depth and interpedicular distance from L1 to L5 in three hundred patients and found the range of interpedicular distance was 17.00 to 43.41 and there is steady increase in the interpedicular distance from L1 to L5.

Sajal R. Et al(57) in their morphometric study of Lumbar pedicle in Indian population. 20 cadavers were studied and measurements were taken directly, Roentgenograms and Computed tomography and found the interpedicular distance gradually increased from L1 to L4 apart from other measurements studied.

In some patients with degenerative disease and other conditions will have altered facet orientation when compared to normal subjects and these changes have been shown to alter the anatomical landmarks for pedicle screw placement. Facet hypertrophy, osteophytes may also alter the normal anatomy of the superior articular facet there by making these structures less amendable for use as anatomical landmarks. (58–60)

In conditions where there is transverse process fracture, revision surgeries the normal anatomical land marks will be distorted and unidentifiable there by making the free hand pedicle screw placement more difficult.

Pars being distinct anatomic area which is often visualized during posterior exposure and is made up of dense cortical bone which rarely becomes arthritic or deformed in degenerative conditions.

The purpose of the present study is to derive the relationship between the lateral border of the pars and medial border of the pedicle from T12 to L4 vertebra. We believe this relationship can be effectively used as a reliable and reproducible alternative anatomical landmark for pedicle screw insertion in the T12 to L4 spine.

METHODOLOGY

Materials:

Cadaver Specimens

Digital Vernier Calipers

Methods:

1. Anatomical Method
2. Radiological Method.

1. <u>Anatomical Method:</u>

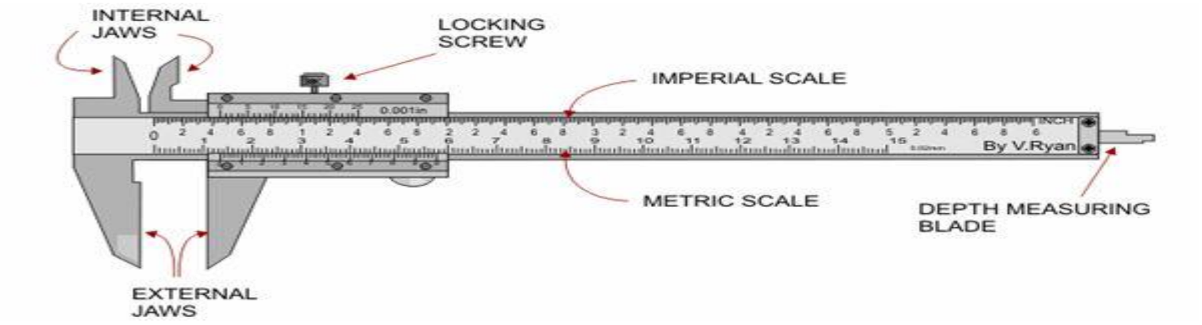
Five cadaveric specimens were used in this study. The cadavers were obtained from the Department of Anatomy Christian Medical College, Vellore, India. Cadaver specimens with fractures or any pathological conditions which altered the morphology grossly were excluded from the study. Cadavers were dissected from their soft tissue attachments and thoraco-lumbar segment was exposed from T11 to L5 with their posterior elements. The soft tissue around the bony portions mainly the lamina, pars interarticularis, transverse process were sharply dissected. The thoraco-lumbar segment extending from T11 to L5 is separated from the cadaver. Further clearance of soft tissue around the pars was performed in order to expose the bone. Care was taken not to nibble any part of the bone over the pars as it may lead to errors while taking measurements.

At each vertebral level (T12-L1; L1-L2; L2-L3; L3-L4; L4-L5) the distance between the right and left pars interarticularis is measured at its narrowest point. After completing the pars measurements the specimens were dissected further from their posterior elements in order to expose the pedicles. The spinous processes were nibbled and laminectomy was performed carefully in a serial fashion starting from mid line towards the periphery using Kerrison rounger. The spinal canal is cleared from its neural structures. The superior and inferior foramen was cleared from their soft tissue and bony structures leaving the pedicles exposed with the facet and the transverse process. The superior facet were carefully nibbled using fine nibbler proceeding from superior to inferior till the pedicle leaving the pedicle exposed with its full length. At every step medial border of the pedicle is carefully palpated and utmost care was taken not nibble the pedicle. Using the internal jaws of the vernier caliper the measurements were taken from the medial most point of the medial border of the both pedicles at each vertebra.

A total of three measurements were taken at each level (pars and pedicle) and average of the three was noted.

Measurements were taken by two different observers

All measurements were taken in millimeters using digital vernire calipers with an accuracy of 0.01MM (INSIZE- SERIES 1112)



LINE DIAGRAM OF VERNIER CALIPERS

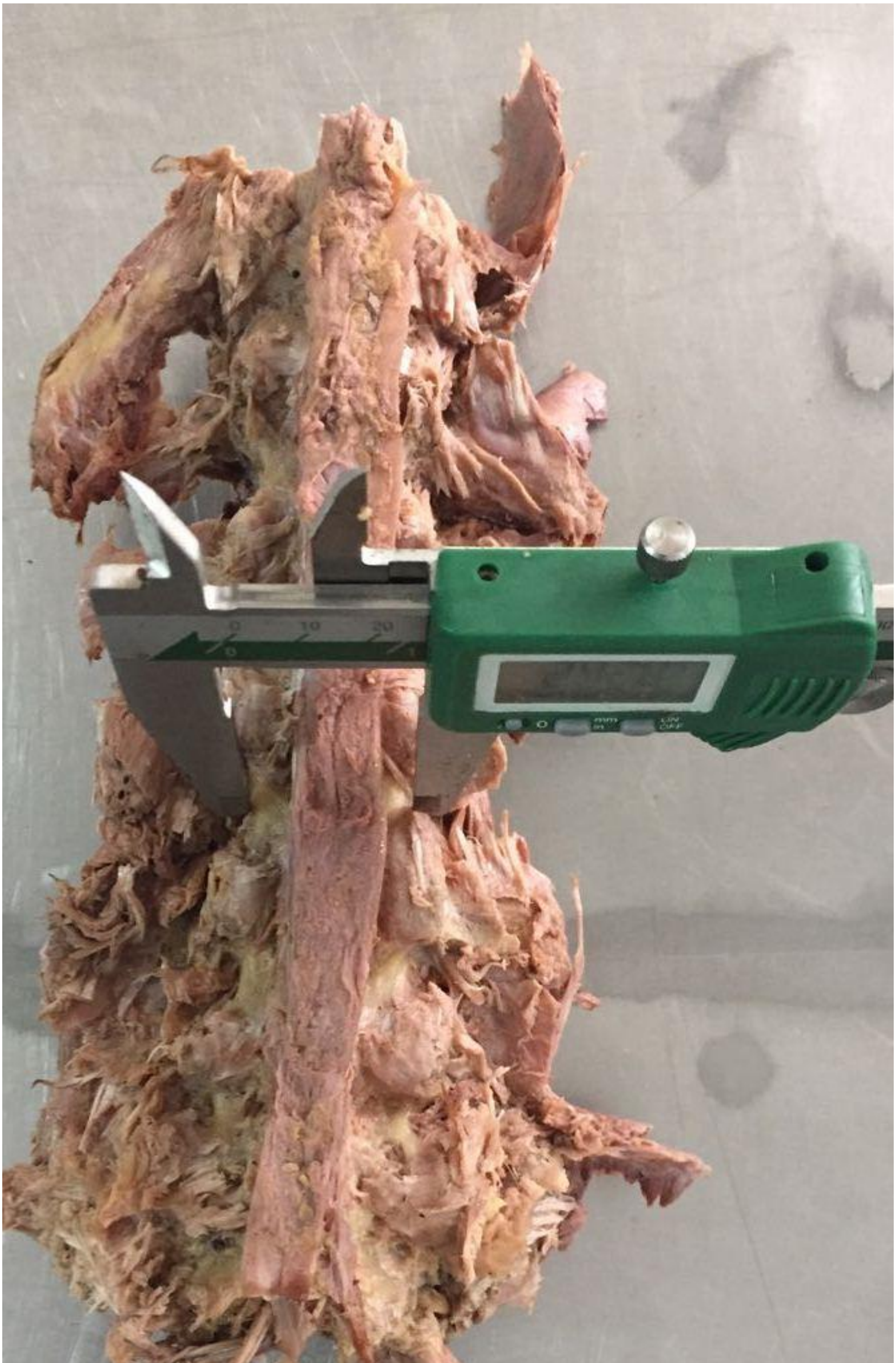
VERNIER CALIPERS USED IN THE STUDY

Dissected Cadaveric Specimen:

Dissected Cadaveric Specimen:

Dissected Cadaveric Specimen Post Laminectomy:

Images showing Inter Pars Distance measured in Cadaveric Specimens:


0
10
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Images showing Inter-Pedicular Distance measured in Cadaveric specimens:

2. Radiological Method:

A total of 100 normal radiographs and 50 normal CT scans were collected from the hospital database of the patients who underwent imaging for routine diagnostic purposes. Radiographs and CT scans with fractures, degenerative conditions or any other pathological disease conditions which altered the normal anatomy were excluded.

On radiographs in order to measure the distance between 2 points, the cursor is placed over the initial reference point using the mouse. The reference point is either the narrowest part of the right and left pars and the medial most point on the medial border of the pedicle.

The cursor is then moved to the opposite side to the second reference point by moving the mouse.

When the button is released, the distance between the 2 points is displayed, reflecting a measurement from the radiographs.

On CT scans the measurements were taken in the coronal plane from the cortical margin of the pars and the pedicle.

All the measurements were taken in Millimeters by two different observers and the values were noted in an Excel sheet.

Stastical analysis was done and inter observer variability was calculated.

The study was approved by Institutional Review Board and there are no conflicts of interest.

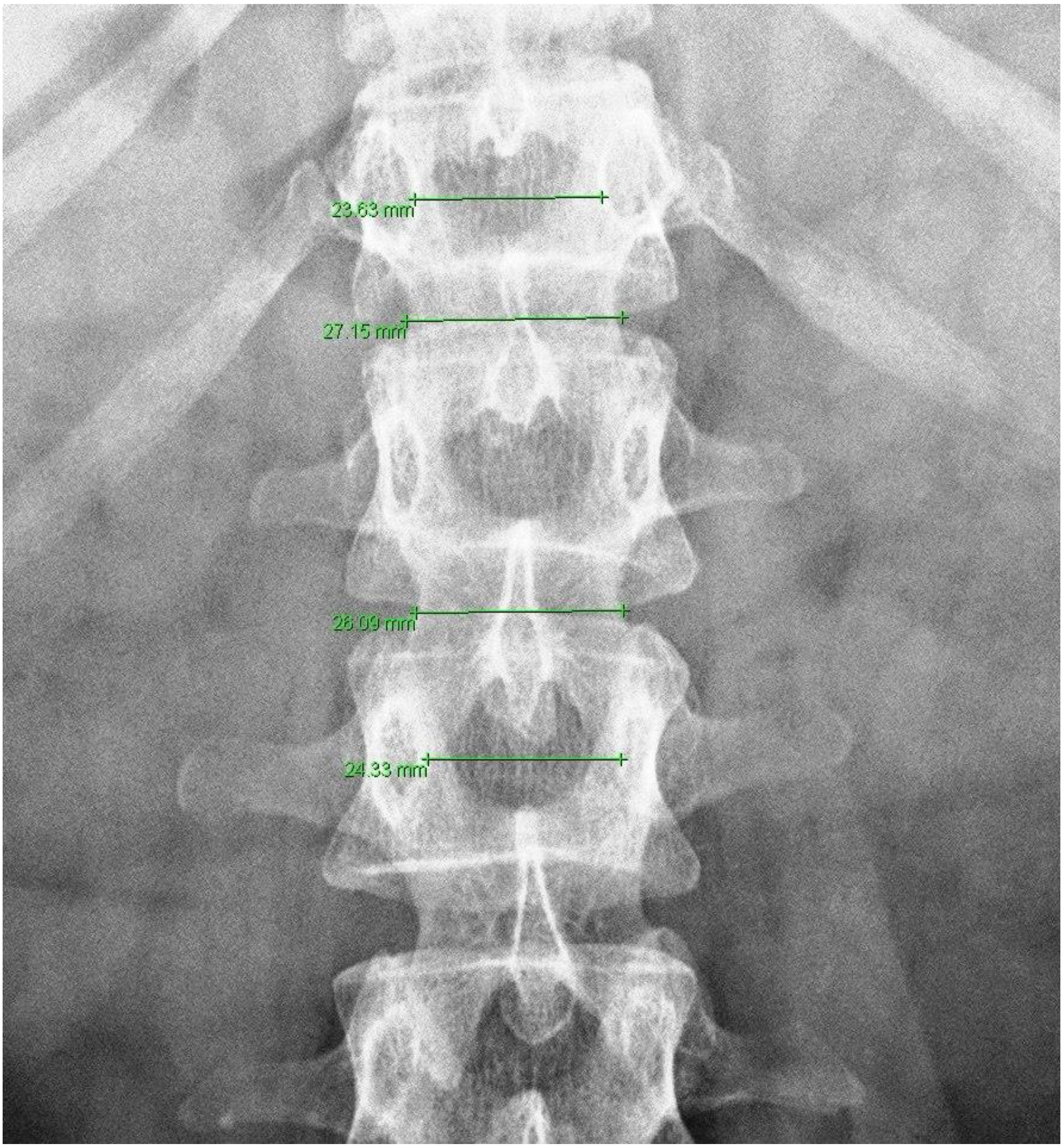


Image showing Measurements on Radiograph 1

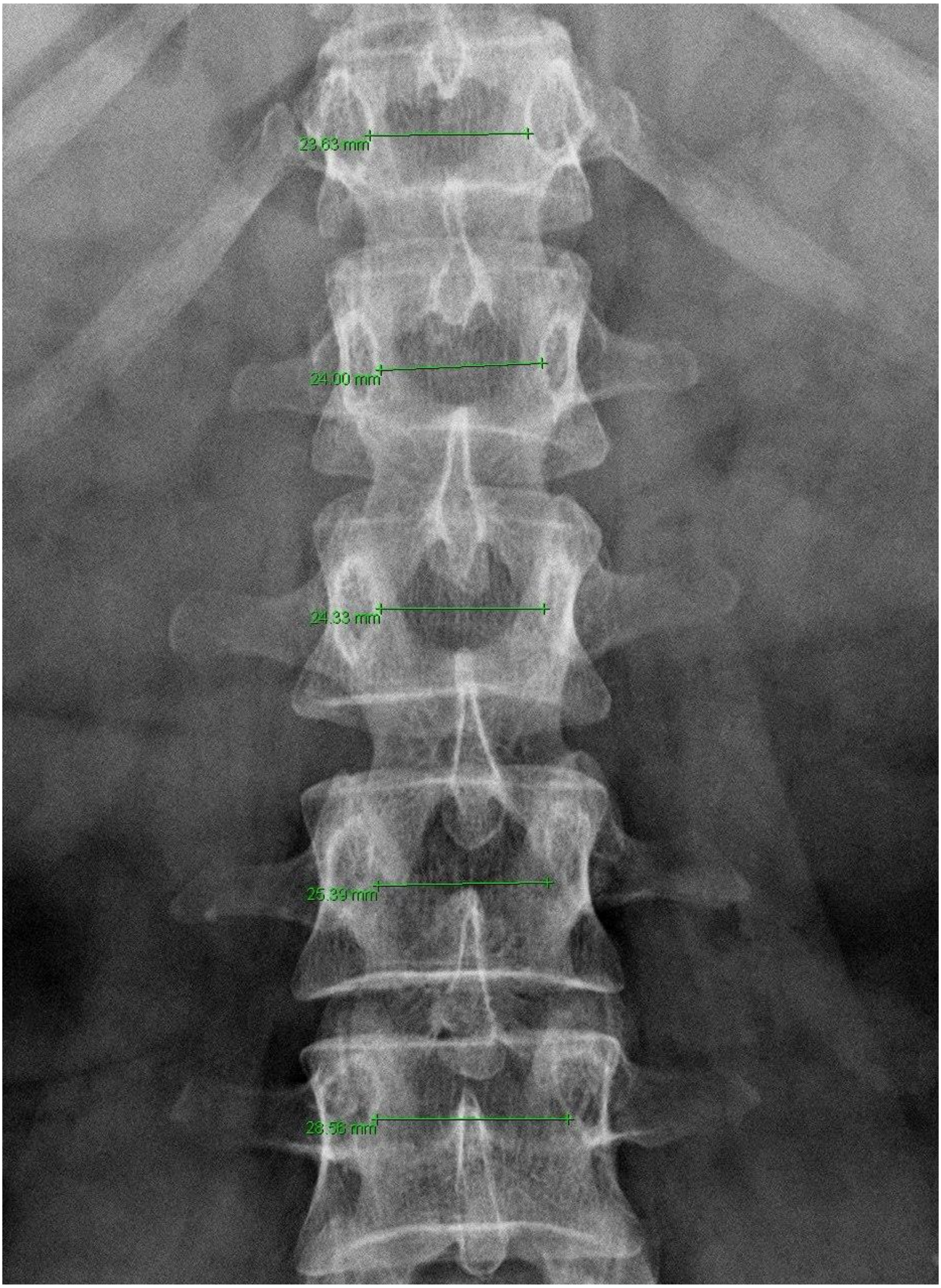


Image showing Measurements on Radiograph 2

Image showing Inter Pedicular Measurements on CT Scan

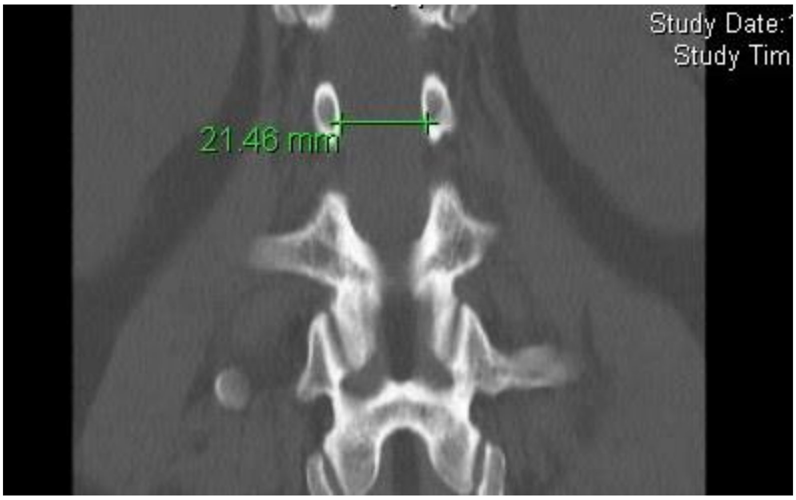
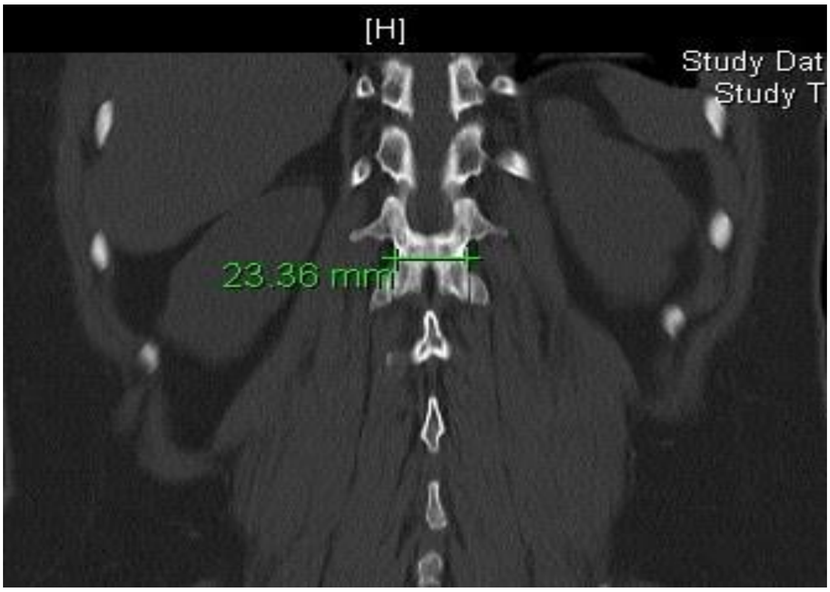
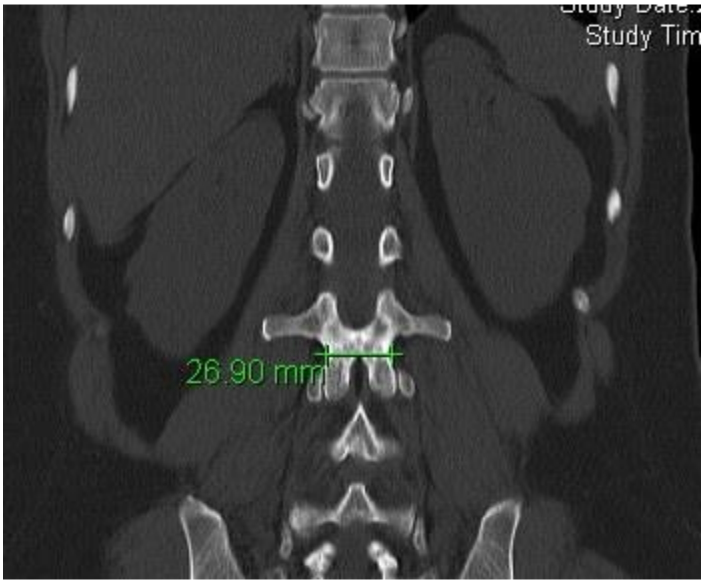


Image showing Inter Pars distance on CT:





RESULTS:

Statistical Methods:

Data entered using Excel and screened for outliers and extreme values using Box-Cox plot and histogram (for shape of the distribution). Summary statistics provided for reporting demographic and clinical characteristics. Reliability test was done for Cadavers, X-ray and CT for Inter Pars distance and Inter Pedicular distance parameters. Differences will be considered significant at $p<0.05$. All the statistical analysis was performed using SPSS 18.0.

Following measurements were taken at all levels from D12 to L4 in all the three groups (cadavers, X rays and CT scans), for convenience each measurement was given an abbreviation. (E.g. Inter Pars Distance is given as Ipr)

1. Inter pars distance (Ipr)
2. Inter pedicular distance (Ipd)
3. Difference of Inter pars and Inter pedicular distance (Ipr-Ipd)
4. Ipr-Ipd/2 assuming that pars and pedicle on right and left side are symmetrical in anatomy and equidistant.

Two observers have measured the values observer 1 being the primary investigator and observer 2 for cadavers is Fellow registrar in Spine and Radiologist for X rays and CT scan measurements. The inter observer reliability was found to be 97.3%, 90.1% and 96.3% for Cadavers, X rays and CT scan measurements with a P value of <0.001

GROUP	**RELIABILITY %**	**P- VALUE**
CADAVERS	97.3%	<0.001
X RAYS	90.10%	
CT SCAN	96.1%	

Cadavers:

Inter Pars Distance (Ipr):

Considering all the cadaveric specimens in both the observers, the average inter pars distances gradually increased from D12 to L4 with a mean of 24.3, 25.2, 29.9, 30.9, and 33.9 mm respectively. The range being 22.8-28.2; 24.0-30.0; 28.1-31.1; 29.9-33.4; and 32.6-36.8 mm at D12; L1; L2; L3 and L4 respectively. There is a significant increase of inter pars distance from L2 to L3 and L3 to L4 and the inter pars distance at D12 and L1 almost remained close.

Inter Pedicular Distance (Ipd):

The averages inter pedicular distance showed steady increase as we moved from D12 to L4 with a mean of 21.3, 22.7, 23.7, 24.9, and 28.3 mm respectively. The range being 19.8-22.9; 21.1-24.0; 22.7-24.6; 23.8-25.6; and 24.8-29.7mm at D12; L1; L2; L3 and L4 respectively . The inter pedicular distance increased in a constant manner of 1 to 1.5mm increments from D12 to L3 and there is significant increase of 3-4 mm from L3 to L4.

Inter pars - Inter pedicular distance (Ipr-Ipd):

The mean difference of the inter pars and inter pedicular distance by both the observers showed a gradual increase from D12 to L4 without significant difference at each level. The mean of Ipr-Ipd are 4.0, 4.2, 5.9, 6.6, and 6.6 mm respectively.

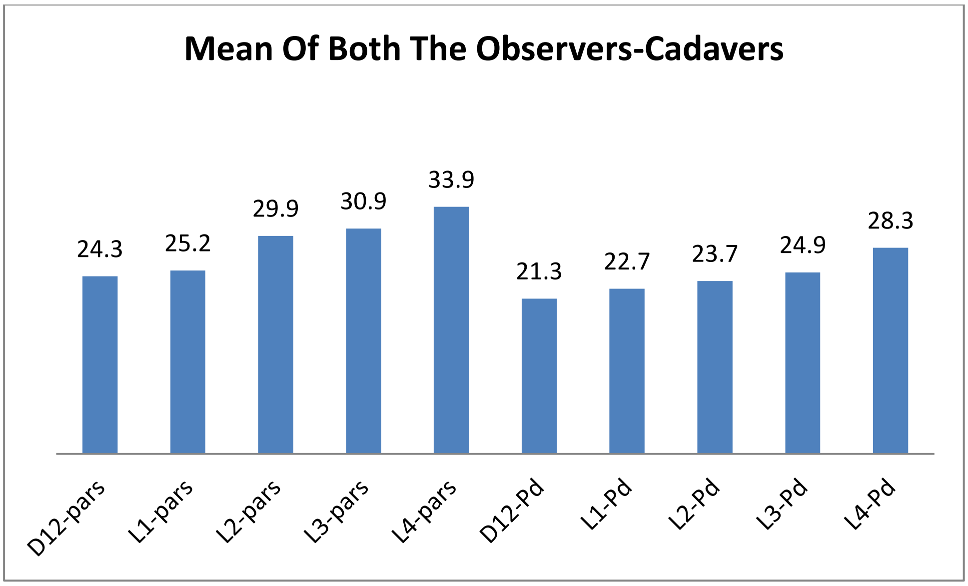
Ipr-Ipd almost remained the same at D12 and L1 and L3 and L4 respectively and with a difference of 1 to 1.5mm at L1-L2 and L2-L3.

<u>Ipr-Ipd/2:</u>

Considering pars and pedicle are symmetrical and equidistant, Ipsilateral distance from the lateral border of the pars and the medial border of the pedicle is calculated by dividing the difference of inter pars and inter pedicular distance by two (Ipr-Ipd/2). The average distance from the lateral border of the pars to that of the medial border of the pedicle on one side are 2.0, 2.1, 2.9, 3.3 and 3.3 mm respectively from D12 to L4 which is very minimal.

CADAVERS:

LEVEL	**INTER-PARS DISTANCE (Ipr) IN MM**	**INTER-PEDICULAR DISTANCE (Ipd) IN MM**	**Ipr-Ipd/2 IN MM**
OBSERVER 1	MEAN	MEAN	MEAN
D12	25.6	21.3	2.1
L1	26.5	22.1	2.2
L2	29.5	23.4	3.1
L3	31.3	24.4	3.4
L4	34.3	27.2	3.5
OBSERVER 2			
D12	25.5	21.7	1.9
L1	26.4	22.5	2.0
L2	29.8	24.1	2.8
L3	31.7	25.2	3.2
L4	34.1	27.9	3.1



X rays:

Inter pars Distance (Ipr):

Of all the 100 normal radiographs studied the mean of inter pars distance measured by both the observers are 25.6; 26.7; 28.5; 30.7; 33.8 mm respectively at D12, L2, L2, L3, L4 respectively showing a gradual increase from D12 to L4 with a minimum increase at D12 and L1. The range being 20.8-29.6; 21.6-30.2; 23.9-32.1; 25.2-33.6; 30.0-36.4 mm at D12, L1, L2, L3, L4 respectively.

Inter Pedicular Distance (Ipd):

The average inter pedicular distance of both the observers is 21.9; 22.8; 24.1; 25.3 and 27.3 mm at D12, L1, L2, L3, L4 respectively. The range being 18.5-25.4; 19.5-26.8; 19.4-27.2; 21.4-29.2 and 22.4-31.1 mm at D12; L1; L2; L3 and L4 respectively. The inter pedicular distance increased in a steady manner from D12 to L3 and there is significant increase from L3 to L4.

Inter pars - Inter pedicular distance (Ipr-Ipd):

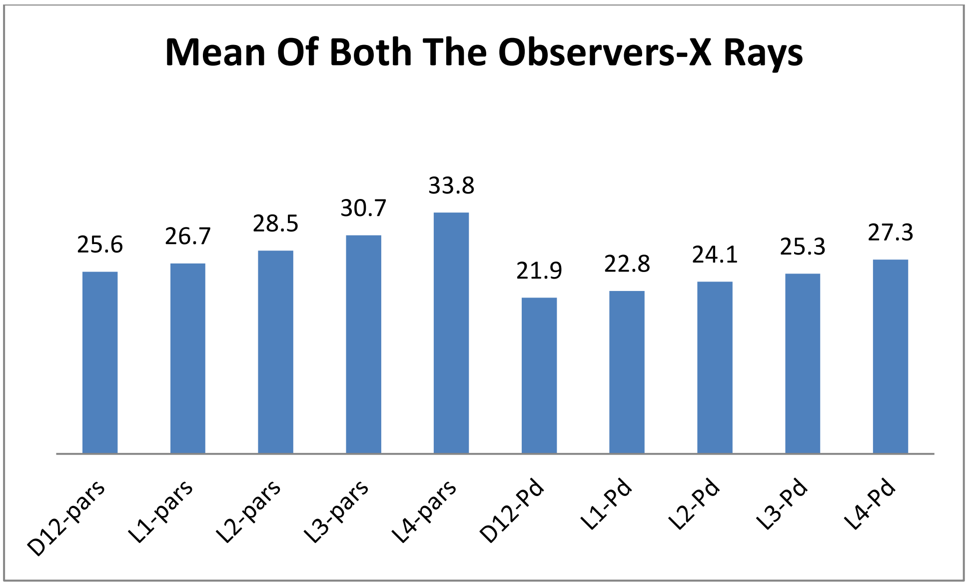
The mean difference of the inter pars and inter pedicular distance by both the observers showed a gradual increase from D12 to L4 without significant difference at each level. The mean of Ipr-Ipd are 3.7, 3.9, 4.4, 5.4, and 6.6 mm respectively.

Ipr-Ipd/2:

The average ipsilateral distance from the lateral border of the pars to that of the medial border of the pedicle on one side are 1.8, 1.9, 2.2, 2.7 and 3.3 mm respectively from D12 to L4.

X-RAYS:

LEVEL	INTER-PARS DISTANCE (Ipr) IN MM	INTER-PEDICULAR DISTANCE (Ipd) IN MM	Ipr-Ipd/2 IN MM
OBSERVER 1	MEAN	MEAN	**MEAN**
D12	25.5	21.8	**1.9**
L1	26.7	22.7	**2.0**
L2	28.6	24.1	**2.2**
L3	30.7	25.0	**2.8**
L4	34.1	27.0	**3.5**
OBSERVER 2			
D12	25.6	22.0	**1.8**
L1	26.8	23.0	**1.9**
L2	28.5	24.2	**2.2**
L3	30.6	25.5	**2.6**
L4	33.6	27.5	3.1



CT Scans:

Inter pars Distance (Ipr):

Measurements were taken from 50 normal CT scans and the mean of inter pars distance measured by both the observers are 22.6; 23.7; 24.5; 26.8; 30.3 mm respectively at D12, L1, L2, L3, L4 respectively showing a gradual increase from D12 to L4. The range being 19.1-28.8; 19.1-29.2; 21.1-30.7; 21.8-33.8; 23.8-38.6mm at D12, L1, L2, L3, L4 respectively.

Inter Pedicular Distance (Ipd):

The average inter pedicular distance of both the observers is 19.1; 19.7; 20.5; 21.4 and 22.6 mm at D12, L1, L2, L3, L4 respectively. The range being 16.6-22.0; 16.2-22.1; 17.9-23.2; 18.2-24.1 and 19.2-25.7 mm at D12; L1; L2; L3 and L4 respectively. The inter pedicular distance increased in a steady manner from D12 to L4.

Inter pars - Inter pedicular distance (Ipr-Ipd):

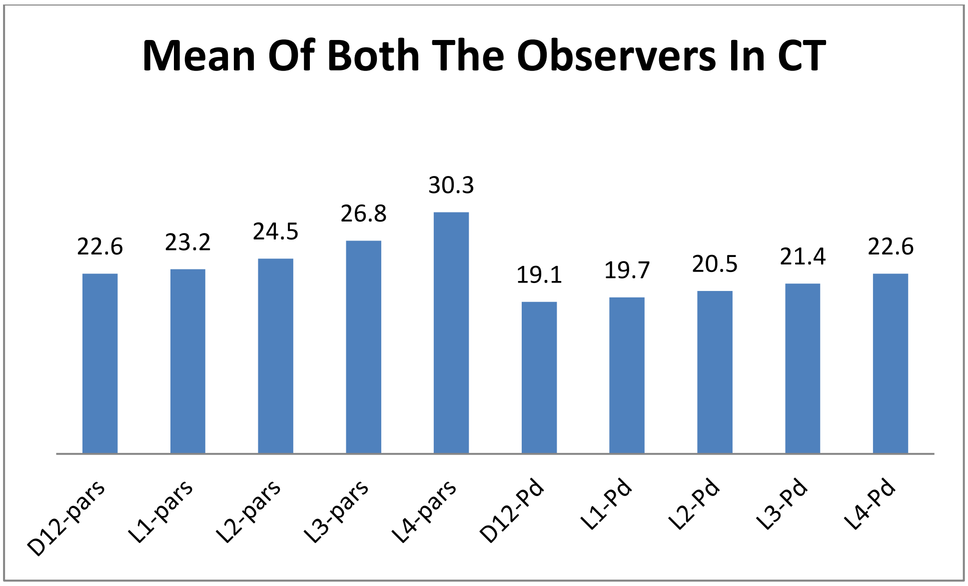
The mean difference of the inter pars and inter pedicular distance by both the observers showed a gradual increase from D12 to L4 with a significant difference at L3 to L4 level. The mean of Ipr-Ipd are 3.6, 3.5, 4.0, 5.4, and 7.7 mm respectively.

Ipr-Ipd/2:

The average ipsilateral distance from the lateral border of the pars to that of the medial border of the pedicle on one side are 1.8, 1.8, 2.0, 2.7 and 3.8 mm respectively from D12 to L4.

CT Scans:

LEVEL	**INTER-PARS DISTANCE (Ipr) IN MM**	**INTER-PEDICULAR DISTANCE (Ipd) IN MM**	**Ipr-Ipd/2 IN MM**
OBSERVER 1	MEAN(SD)	MEAN(SD)	MEAN
D12	22.8	18.9	1.9
L1	22.9	19.3	1.8
L2	24.2	19.9	2.1
L3	26.6	20.9	2.8
L4	30.5	21.9	4.3
OBSERVER 2			
D12	22.5	19.2	1.6
L1	23.5	20.0	1.7
L2	24.8	21.0	1.9
L3	26.9	21.8	2.5
L4	30.2	23.4	3.4

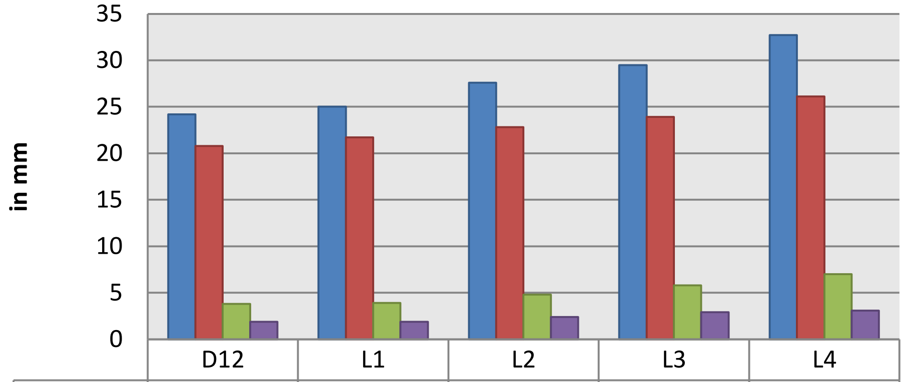


The Mean of Inter pars distance(Ipr), Inter Pedicular distance(Ipd), Inter pars-Inter pedicular distance(Ipr-Ipd) and ipsilateral distance(Ipr-Ipd/2) at all levels (D12-L4) across cadavers, X-rays and CT scan is shown in the table below.

<u>Mean Of Ipr, Ipd, Ipr-Ipd, and Ipr-Ipd/2 Of Both The Observers In All Three Groups:</u>

	D12	L1	L2	L3	L4
Ipr	24.2	25.0	27.6	29.5	32.7
Ipd	20.8	21.7	22.8	23.9	26.1
Ipr-Ipd	3.8	3.9	4.8	5.8	7.0
Ipr-Ipd/2	1.9	1.9	2.4	2.9	3.1

GRAPH SHOWING MEAN OF ALL MEASUREMENTS OF BOTH OBSERVERS:

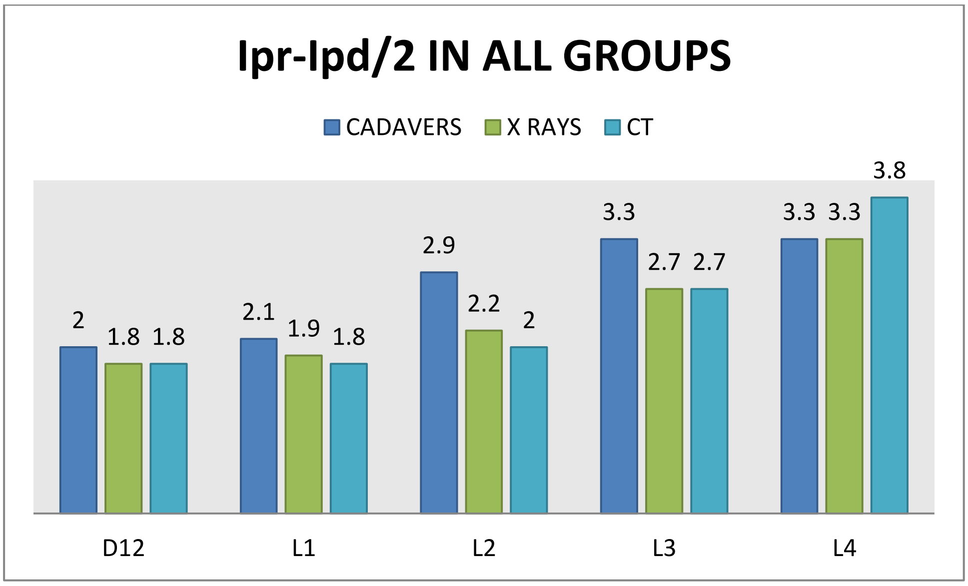


	D12	L1	L2	L3	L4
Ipr	24.2	25	27.6	29.5	32.7
Ipd	20.8	21.7	22.8	23.9	26.1
Ipr-Ipd	3.8	3.9	4.8	5.8	7
Ipr-Ipd/2	1.9	1.9	2.4	2.9	3.1

In the present study we aimed at studying the relationship between the lateral border of the pars to that of the medial border the pedicle. Ipr-Ipd/2 gives the ipsilateral distance measured on one side assuming pars and pedicle are symmetrical on both sides. The Ipr-Ipd/2 is compared among the three groups and shown in the following table.

Comparison Of Mean Ipr-Ipd/2 By Both The Observers In All Groups:

GROUP	D12	L1	L2	L3	L4
CADAVERS	2	2.1	2.9	3.3	3.3
X RAYS	1.8	1.9	2.2	2.7	3.3
CT	1.8	1.8	2	2.7	3.8

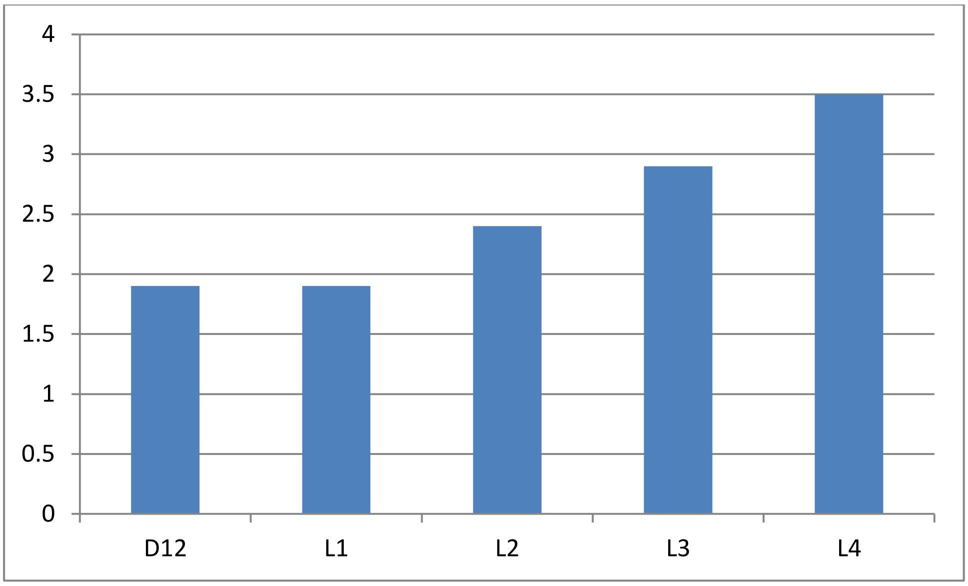


The average of Ipr-Ipd of the all the groups by both observers is shown below.

Mean Ipr-Ipd/2 by both the observers in all groups:

	D12	L1	L2	L3	L4
Mean	1.9	1.9	2.4	2.9	3.5

Mean Ipr-Ipd/2 by both the observers in all groups:



DISCUSSION:

Pars interarticularis playing a key role in adding structural support to the spinal column yet there is not much literature available on its anatomic feature and its relationship to the surrounding spinal canal structures.

There were significant studies describing the morphometry of the posterior elements of the vertebral body and their relation to the neural structures. There were equal number of morphometric analysis of the posterior elements and their relationship in guiding the entry point for the pedicle screw placement. The relationship of the bony anatomical landmarks namely transverse process, superior facet joint, pars interarticularis were studied in detail by various authors to define ideal anatomical land mark for guiding the entry point for the pedicle screw insertion.

Free hand technique for placing the pedicle screw has gained its importance and is more used compared with assisted navigation methods there by decreasing the radiation hazard and saving the operating time. With the studies showing increased accuracy and ease of placing the pedicle screw with safety along with minimal risks involved in placing the screw given that the operating surgeon was aware of the importance of the anatomical landmarks and adequate training. With all the added advantages like providing three dimensional stability, increased fusion rates, not needing intact posterior elements pedicle screw gained its importance and has been the preferred method for pedicle screw insertion.

Among the land marks that guide the pedicle screw placement pars being made up of dense cortical bone and not easily deformed in degenerative conditions, there were few studies that were done on the relationship between the pars interarticualris and the pedicle. There were studies documented on the inter pars distance at lumbar level by Austin peters et al(53) analyzed 265 vertebra and demonstrated that there is gradual increase in the inter pars size from L1 to L4 and the inter pars distance increased dramatically from L4 to L5 and also found that the trend was similar in both males and females.

Austin Peters et al

LEVEL	INTER PARS DISTANCE
L1	24MM
L2	25MM
L3	27MM
L4	32MM
L5	41MM

In one study by E. Yee et al(52) in their cadaveric study measured the average width of the pars remained from L1 to L5 vertebra from the medial edge of the pedicle on the ipsilateral side following a serial laminectomy from midline to the medial border of the pedicle. The values are shown below

E. Yee et al:

LEVEL	REMNANT PARS	RANGE
L1	4mm	3-6mm
L2	6mm	5-7mm
L3	8mm	4-9mm
L4	11mm	9-14mm
L5	16mm	13-17mm

In separate studies Inter pedicular distance was documented by various studies in an attempt to study the dimensions of the spinal canal.

Tarek Aly et al(56) measured the Interpedicular distance along with other parameters in 300 normal Egyptian population using CT scan from L1 to S1and demonstrated that the inter pedicular distance showed a steady increase from L1 to L5

Tarek Aly et al:

VERTEBRA	MEAN INTER PEDICULAR DISTANCE AND RANGE IN MM
L1	28.83(17.00-30.59)
L2	24.30(17.08-34.33)
L3	25.72(19.10-36.65)
L4	27.29(18.00-37.79)
L5	31.46(21.10-43.41)

In another morphometric study in Indian population by Yael Kapoor et al(55) in their cadaveric study measured the inter pediculate distance from L1 to L5 vertebra and reported the average interpedicular distance ranged from 18.51mm – 21.50 mm at L1, L5 levels and at L2 - L4 is 21.47mm, which showed a steady increase in the interpedicular distance from L1 to L5 vertebra.

Sajal R et al(57) in their study on Lumbar vertebra reported that the interpedicular distance increased gradually from L1 to L4 both genders. The radiological values were significantly higher than the direct measurements at all levels which are attributed to the overlap of the pedicles in radiographs.

In the present study it was observed the inter pars and the inter pedicular distance gradually increased from D12 to L4 in all the groups cadavers, X rays and CT scan. The mean Inter pars and Inter pedicular distance from D12 to L4 in all the groups is shown below:

Mean of Inter Pars and Inter Pedicular distance in all groups from D12 to L4 in MM.

	D12	L1	L2	L3	L4
Ipr	24.2	25.0	27.6	29.5	32.7
Ipd	20.8	21.7	22.8	23.9	26.1

Mean Of Ipr, Ipd, Ipr-Ipd, and Ipr-Ipd/2 Of Both The Observers In All Three Groups in MM:

	Ipr	Ipd	Ipr-Ipd	Ipr-Ipd/2
D12	24.2	20.8	3.8	1.9
L1	25	21.7	3.9	1.9
L2	27.6	22.8	4.8	2.4
L3	29.5	23.9	5.8	2.9
L4	32.7	26.1	7	3.1

We went ahead further in deriving the distance from the lateral border of the pars inter articularis to that of the medial border of the pedicle. Assuming that pars inter articualris and pedicle on right and left side are symmetrical in their anatomy and equidistantly placed, the Inter pars distance minus Inter pedicular distance when divided into half (Ipr-Ipd/2) gives distance on one side i.e., distance between the lateral border of the pars inter articularis to that of the medial border of the pedicle.

<u>Comparison of Ipr-Ipd/2 in all the groups in MM:</u>

	D12	L1	L2	L3	L4
CADAVERS	2	2.1	2.9	3.3	3.3
X RAYS	1.8	1.9	2.2	2.7	3.3
CT	1.8	1.8	2	2.7	3.8

<u>Mean Ipr-Ipd/2 by both the observers in all groups in MM:</u>

	D12	L1	L2	L3	L4
Mean	1.9	1.9	2.4	2.9	3.5

So the mean distance from the lateral border of the pars to that of the medial border of the pedicle in the cadavers almost remained constant except for a few mm variations. Vaccaro et al(40) in 2008 in their Anatomical study described the relationship between pedicle center to the Mid-Lateral pars in lower Lumbar vertebra L3 to S1, as a guide to pedicle screw placement and concluded that mid lateral pars is a reliable anatomic reference. They reported that in medial-lateral direction, the pedicle centre is 2.9 mm lateral to the MLP at L3 and L4 respectively and L5, it is 1.5 and 4.5 mm lateral to the MLP for a type I and type II L5 pedicle, respectively. The percent of pedicle lateral to the MLP is 77% and 71% at L3 and L4. At L5, it is 58% and 70% for type I and type II pedicle respectively.

Form the present study it was found that the lateral border of the pars interarticularis lies in close relationship with that of the medial border of the pedicle from D12 to L4. This relationship helps in choosing the medio-lateral entry point with pars as a reference anatomical landmark.

The clinical implications being- pars inter articularis is routinely seen in all the posterior exposures and easy to identify due to its dense cortical nature and rarely get altered due to the degenerative changes unlike facet joints. As long as one stays on to the lateral border of the pars or few mm lateral to the lateral border of the pars inter articularis in medio lateral direction the chances of breaching the medial border of the pedicle can be minimized.

By the this study we found a new relationship between the lateral border of the pars interarticularis to that of the medial border of the pedicle from D12 to L4 and there by describing a new method in defining a the entry point in medio-lateral direction using lateral border of the pars interarticularis as consistent anatomical land mark.

CONCLUSIONS

Inter pars distance and Inter Pedicular distance showed a steady increase from D12 to L4 vertebra.

The lateral border of the pars inter articularis lies in close relationship to the medial border of the pedicle from D12 to L4 vertebra.

The lateral border of the pars interarticularis can be used as a consistent anatomical land mark in defining the entry point in medio-lateral direction for the pedicle screw insertion in lumbar spine.

LIMITATIONS:

Measurements were not taken in same subjects in all the groups.

Magnification in the radiological part was not accounted for

In spite of every effort taken in order to minimize the errors while taking the measurements there are still chances of errors to have occurred

Though we have collected Radiographs and CT scans of normal subjects from our data base there are chances of altered anatomy due to subtle degenerative changes.

Further Directions:

As we are dealing with the measurements in millimeters one can focus on establishing concrete methodology by studying same ethnic group and documenting both the anatomical radiological parameters.

Further study should focus on clinical application of using lateral border of the pars as consistent anatomical land mark and evaluating its accuracy compared with other methods.

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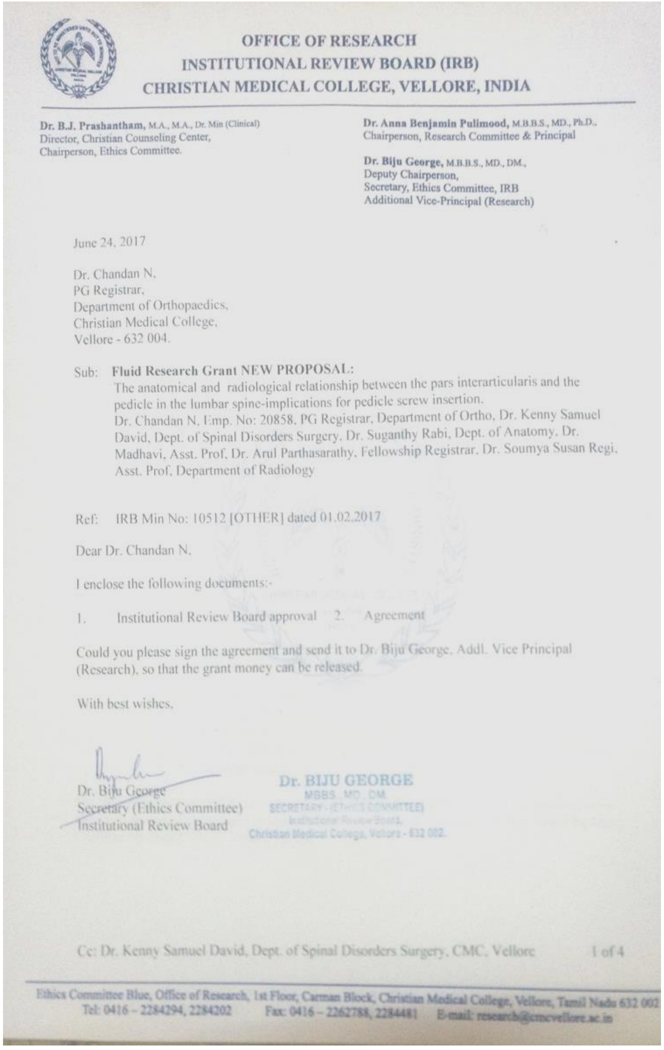
ANNEXURES

SCANNED COPY OF IRB LETTER



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June 24, 2017

Dr. Chandan N.
PG Registrar,
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Sub: **Fluid Research Grant NEW PROPOSAL:**
The anatomical and radiological relationship between the pars interarticularis and the pedicle in the lumbar spine-implications for pedicle screw insertion.
Dr. Chandan N, Emp. No: 20858, PG Registrar, Department of Ortho, Dr. Kenny Samuel David, Dept. of Spinal Disorders Surgery, Dr. Suganthy Rabi, Dept. of Anatomy, Dr. Madhavi, Asst. Prof, Dr. Arul Parthasarathy, Fellowship Registrar, Dr. Soumya Susan Regi, Asst. Prof, Department of Radiology

Ref: IRB Min No: 10512 [OTHER] dated 01.02.2017

Dear Dr. Chandan N,

I enclose the following documents:-

1. Institutional Review Board approval 2. Agreement

Could you please sign the agreement and send it to Dr. Biju George, Addl. Vice Principal (Research), so that the grant money can be released.

With best wishes,

Dr. Biju George
Secretary (Ethics Committee)
Institutional Review Board

Dr. BIJU GEORGE
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SECRETARY - (ETHICS COMMITTEE)
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Cc: Dr. Kenny Samuel David, Dept. of Spinal Disorders Surgery, CMC, Vellore

1 of 4

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THESIS DATA